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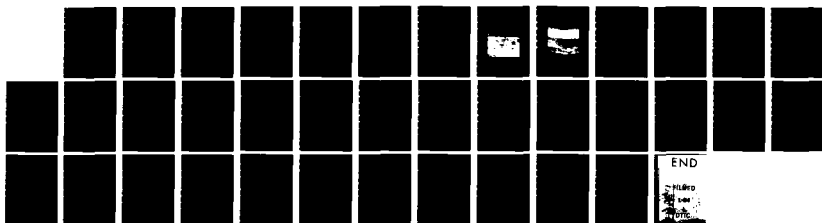
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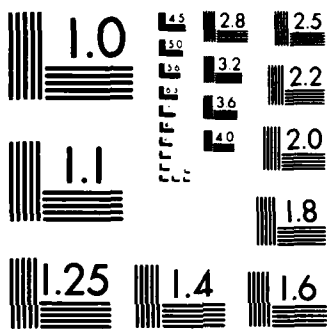
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study involves thermal infrared measurement for the determination of the diurnal and seasonal aspects of the relations between isolated evergreen trees and a cut grass background and between a large truck brightness temperature and cut grass, uncut grass, and bare soil backgrounds. Seasonal changes in the tree brightness temperature-background brightness temperature contrast ranged from 4 to 5°C in February and March to 1 to 2°C in July. At night, the thermal contrast between trees and background was found to vary inversely with long wave incoming radiation, which is a measure of cloudiness. A study of the change in the thermal

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contrast during the night showed that, during clear weather, the contrast was at a peak a few hours after sundown and decreased the rest of the night. In overcast conditions, a reduced contrast peak occurred at sundown and very gradually diminished through the night. Isothermal conditions were found to occur in the early mornings, and the time of these occurrences changed seasonally, in a systematic manner.

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The Relation Between Isolated Tree Brightness  
Temperature and Grass Background Brightness Temperature

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ABSTRACT

This study involves thermal infrared measurement for the determination of the diurnal and seasonal aspects of the relations between isolated evergreen trees and a cut grass background and between a large truck and cut grass, uncut grass, and bare soil backgrounds. Seasonal changes in the tree brightness temperature-background brightness temperature contrast ranged from 4 to 5°C in February and March to 1 to 2°C in July. At night, the thermal contrast between trees and background was found to vary inversely with long wave incoming radiation, which is a measure of cloudiness. A study of the change in the thermal contrast during the night showed that, during clear weather, the contrast was at a peak a few hours after sundown and decreased the rest of the night. In overcast conditions, a reduced contrast peak occurred at sundown and very gradually diminished through the night. Isothermal conditions were found to occur in the early mornings, and the time of these occurrences changed seasonally, in a systematic manner.

INTRODUCTION

In a downward-looking, airborne, nighttime, thermal image, isolated trees frequently appear as relatively warm objects against a cooler background. When the spatial resolution is too poor to resolve the

shapes of objects, isolated trees can be mistaken for such things as motor vehicles . Leighty, Vogel (1965).

The temperatures of objects in a scene and their backgrounds change diurnally, and the diurnal pattern changes seasonally. Real, measured data are required to understand the relationships and to predict relative temperatures of various objects and various backgrounds.

We are interested in the thermal, radiometric measurement of temperatures for application with airborne thermal imagers and ground based imaging systems. To use these tools we must also understand the relation of the image seen to the scene itself and how the imager works.

Thermal infrared scanners and infrared radiometers integrate over an area covered by their instantaneous field of view. If that field of view covers most of a tree, they will produce a signal proportional to the average temperature of the whole tree. They measure irradiance, or the radiant power per unit area incident upon, and responded to, by an infrared detector. The radiant power per unit area emitted by an object is described by Planck's Law, and when that is integrated over all wavelengths, a more simple expression, the Stefan-Boltzman Law, results:

$$M = \epsilon \sigma T^4$$

where

M = Total radiant emittance, Watts/meter<sup>2</sup>

$\sigma$  = The Stefan-Boltzmann constant,  $5.67 \times 10^{-8} \text{ W/m}^2 (\text{degrees K})^4$

T = Absolute temperature, degrees Kelvin

$\epsilon$  = The emissivity, or the ratio of the rate of radiant energy emission from a body, as a consequence of its temperature only, to the corresponding rate of emission from a blackbody at the same temperature. Wolfe (1965), Smith et al (1968)

The emitted energy, while mostly temperature dependent, is also affected by the value of the emissivity. A blackbody has an emissivity of 1, and reemits all received energy, but natural objects and most man made objects are not blackbodies and have emissivities of less than 1. The average emissivity of a tree is unknown, so the actual temperature cannot be computed accurately. Therefore we relate the value of irradiance, which we measure, to the brightness temperature of the tree. The brightness temperature is the temperature of a blackbody having the same emission per unit area as the actual radiator. It follows that the brightness temperature is always less than the actual temperature of the body. Smith et al (1968).

#### PURPOSE

In a previous study we have substantiated that isolated tree brightness temperature, measured radiometrically, follows air temperature, at night. In this study we investigated the relation between the isolated tree brightness temperature and a grass-covered background brightness temperature, which is "clutter" in thermal infrared images. The isolated tree can also represent other objects standing above a grass background and tending to follow the air temperature. Measurements of radiometric temperature of cut and uncut grass, bare soil, and a large truck (engine off) were made and analyzed to expand the understanding of temperature contrast between objects in a scene and their backgrounds and give a measure of the amplitudes of temperature to expect. The questions to be asked are, what are the diurnal and seasonal effects upon the temperature difference between trees and other objects and their backgrounds? What other parameters affect these differences?

The answers to these questions will greatly enhance our ability to interpret thermal images for environmental and engineering applications and for military target/background discrimination applications.

#### DESCRIPTION OF EXPERIMENT

The experiments took place at a test facility at Ft. Belvoir, VA. Two evergreen trees were located on a cut grass surface, 13.7m from an infrared radiometer (Barnes PRT-5), having a  $2^{\circ}$  FOV and a spectral range of 8 to 14  $\mu$ m. The PRT-5 was positioned 2.4m above the center of mass of the trees and so was aimed  $10^{\circ}$  below the horizontal. The single PRT-5 was scanned, with a stepping motor in a wide arc to measure the brightness temperature of three spots on the grass surface and the two trees. The trees were a 217 cm Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) and a 215 cm arborvitae (Thuia plicata, Donn). A total of 5400 scans were made on the trees, of which 3500 were made at night, in dry conditions, from February to July, 1981. See Figure 1.

In the following year, a similar PRT-5, with a  $4^{\circ}$  FOV was mounted 13.7m up on a tower and scanned across two cut grass plots, an uncut grass plot, a bare soil plot, and a large truck (engine off). The angle of incidence was about  $45^{\circ}$  with the radiometer facing south. Scans were made every 8 minutes at night and every 20 minutes during the day. A total of 2800 scans were made of the plots and truck, at night, in dry conditions, from June to September, 1982. See Figure 2.

Night was defined as Short Wave Incoming (Swi) Radiation, or insolation,  $< 30 \text{ W/m}^2$ . Most meteorological and radiometric parameters and many air and soil temperatures were also measured during these scans, automatically by a data logger (Doric 220) controlled by a desktop computer

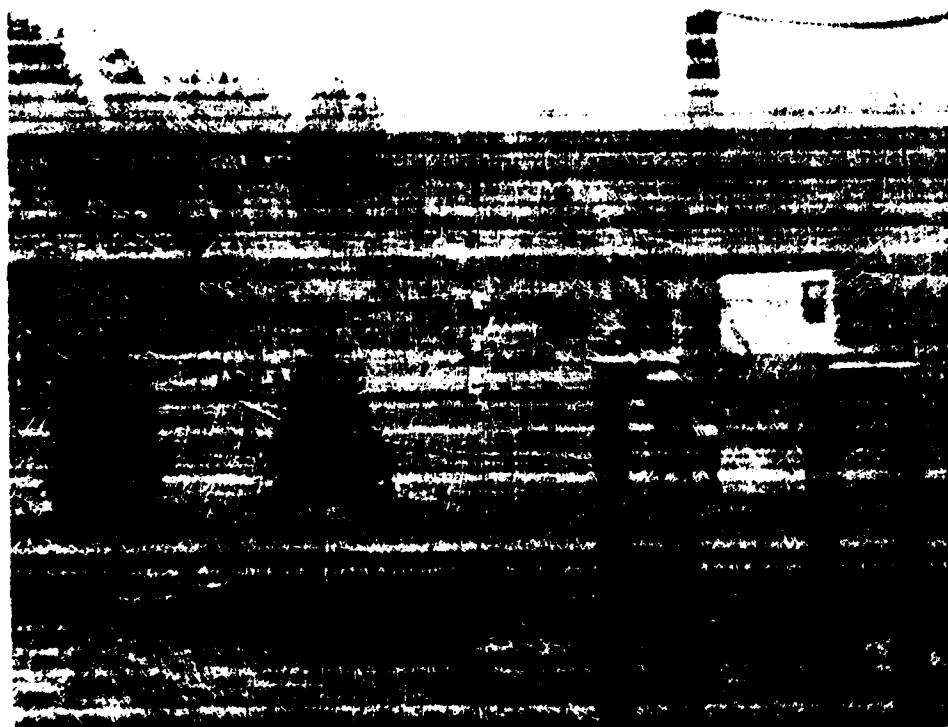


Figure 1. Photograph of 1981 tree vs. background experiment setup, showing infrared radiometer in housing in foreground and trees in middleground.

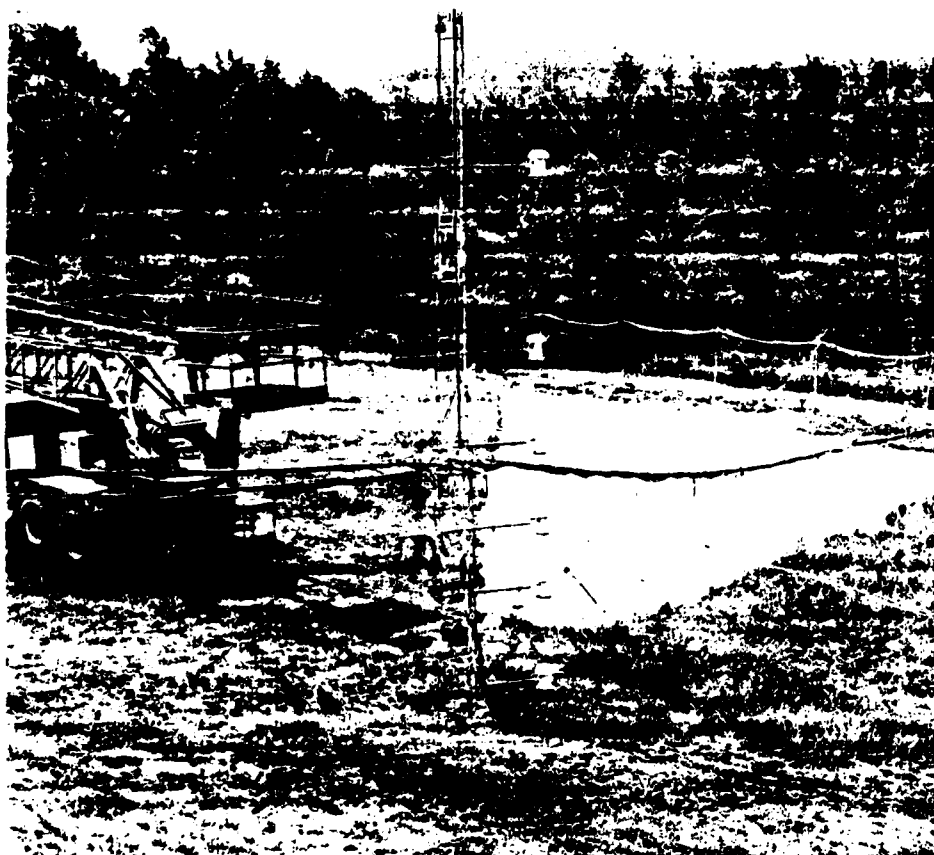


Figure 2. Photograph of 1982 truck vs. background experiment setup, showing, from left to right, the large truck, cut grass, bare soil, and uncut grass. The truck faces southeast.

(HP9845T). See Appendix A for parameters measured. The scanned infrared radiometer allowed good temperature sensitivity ( $<0.1^{\circ}\text{C}$ ) between targets, as only a single instrument was used for all measurements. Each scan averaged 10 observations of each target by the infrared radiometer.

The experimental approach was: (1) to compare average tree brightness temperature with average grass brightness temperature, over diurnal and seasonal cycles; (2) to compare truck brightness temperature to the brightness temperatures of various backgrounds, over diurnal and seasonal cycles; (3) to compare the difference of tree brightness temperature—background brightness temperature to long wave incoming radiation (Lwi); (4) to compare the tree-background brightness temperature difference (thermal contrast) to the time from sundown; and (5) to determine time relationships when the tree-background brightness temperature difference was zero and when the normalized air temperature profile was also zero and "isothermal" conditions existed.

## RESULTS

### Tree Brightness Temperature Versus Background Brightness Temperature

The difference in brightness temperature between the two kinds of evergreens was monitored, and over the whole period the average brightness temperature difference between them was  $0.1^{\circ}\text{C}$ . Thus the two values were averaged and are referred to as tree brightness temperature. The brightness temperature of the three cut grass background spots was also averaged and are hereafter referred to as background brightness temperature.

In general, the trees were up to 5°C warmer than the background at night and colder by day, so a temperature reversal occurred twice in each 24 hour period - in the morning and evening.

#### Diurnal Cycle of Tree-Background Brightness Temperature Difference

See Figure 3, Tree Average Brightness Temperature, Background Average Brightness Temperature, and Air Temperature versus Time of Day and Day of the Year, 1981. Daytime background temperature was highly correlated with solar insolation (Swi). During the day the background warmed up hotter and more quickly than did the trees and the air, but after noon it declined as the short wave incoming radiation declined. Past solar noon, the ground started to loose heat downward by conduction through the soil, and the grass by transpiration and radiation, faster than heat was received by solar illumination, and the surface cooled. Temperature profiles of the soil and the air showed that, through the afternoon, the air temperature continued to increase slowly, the surface temperature decreased quickly, and the subsurface temperature increased slowly. Energy received at the surface apparently was transferred into the ground by conduction and back into space by radiation and transpiration, causing the surface temperature to decrease quickly after solar noon. See Figure 4, Height versus Temperature. The trees and the air continued to warm as more solar input was received, even though at a reduced level. By about 1600 hours the ground and trees had reached the same temperature - the ground by cooling, and the trees by heating. After cessation of solar heating, the background cooled very quickly by radiation, transpiration, and by conduction into the subsoil. The trees and air began cooling, but at a slower rate, by radiation only. Sutton (1953) said that "...in the

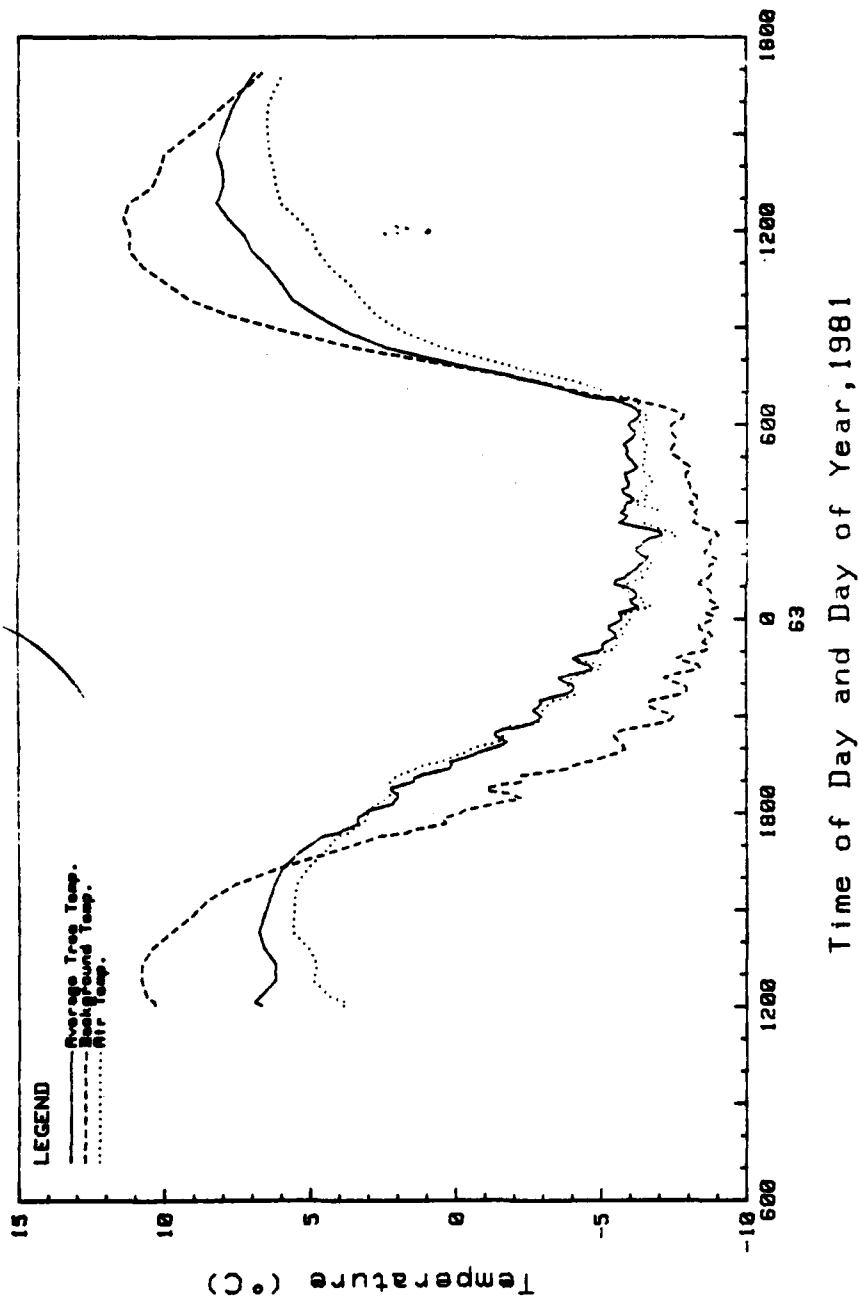


Figure 3. A typical diurnal cycle of the Average Brightness Temperature of the trees and the grass background and the air temperature, on 3 and 4 March 1981.

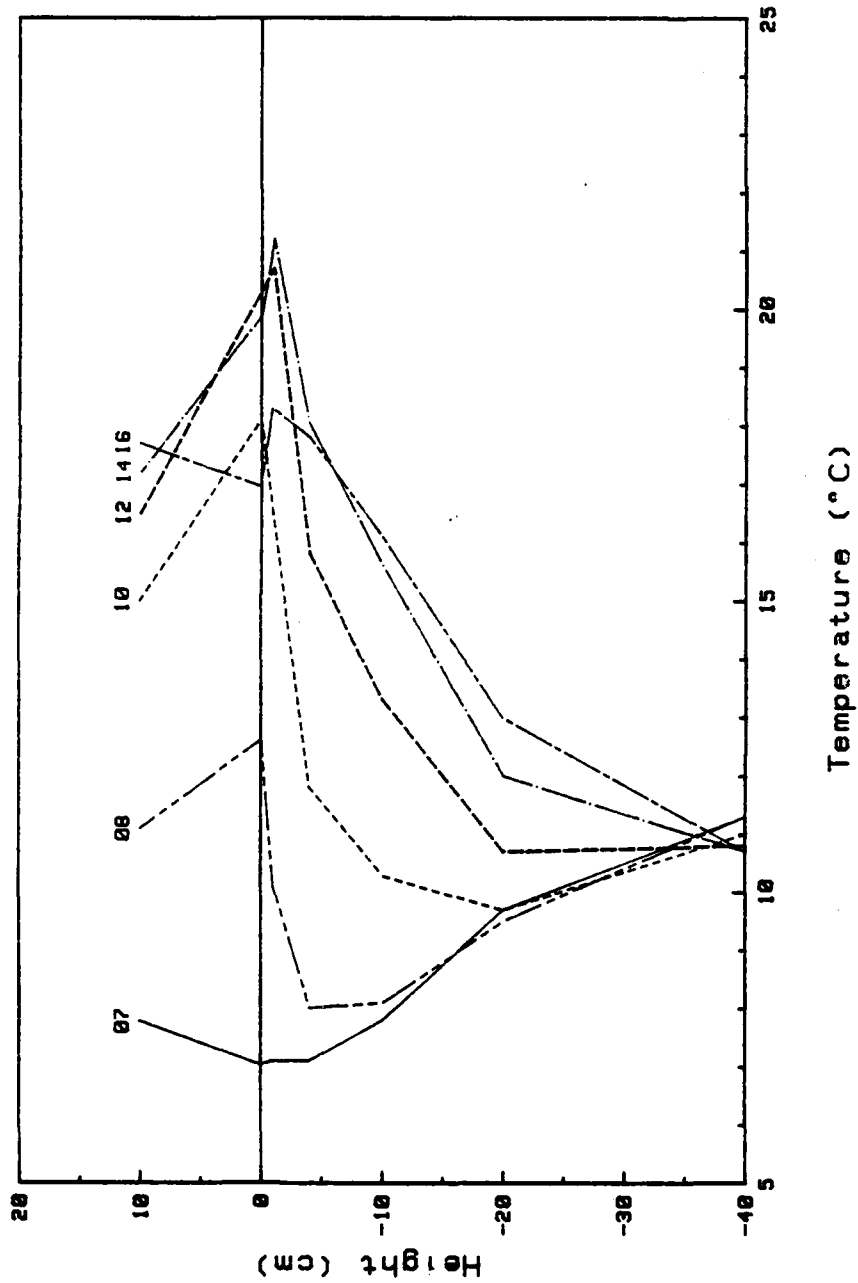


Figure 4. Temperature profile including air temperature, cut grass surface brightness temperature, and soil temperatures, for 7 April 1981, from 1720 to 1620. This shows how afternoon surface temperatures decrease quickly while air and subsurface temperatures increase slowly.

evening, cooling of the atmosphere starts at the lowest level and slowly ascends to the greater heights." These two effects caused the tree brightness temperature to appear much warmer than the background brightness temperature for a brief time. After equilibrium was reached in the darkened environment, a fairly uniform decrease in temperature difference prevailed, with the trees near air temperature, above background temperature, initially by as much as  $5^{\circ}\text{C}$ . At first light, the background quickly warmed up to the same temperature as the trees and the air, and all increased in temperature together to a point of separation. The background, then, continued to warm at a high rate while solar insolation was still increasing. The trees and the air warmed at much lower rates through the early morning, but continued at those rates until afternoon, while background temperature had peaked and started to decrease. The lower soil layers acted as a heat sink for the ground surface, while the trees and air had no such reservoir.

#### Seasonal Change of Tree-Background Brightness Temperature Difference

In the winter and early spring (February, March), the nighttime contrast between the trees and the background was about  $2-5^{\circ}\text{C}$ , but by summer (July) it had dropped down to  $1-2^{\circ}\text{C}$ . In the winter and early spring the rate of change of the temperature difference, at the crossover times - morning and evening - was much faster than in the summer. See Figures 5 and 6, Tree-Background Brightness Temperature versus Time of Day and Day of the Year, 1981. Table 1 summarizes seasonal characteristics of the tree, grass background, and the air temperatures.

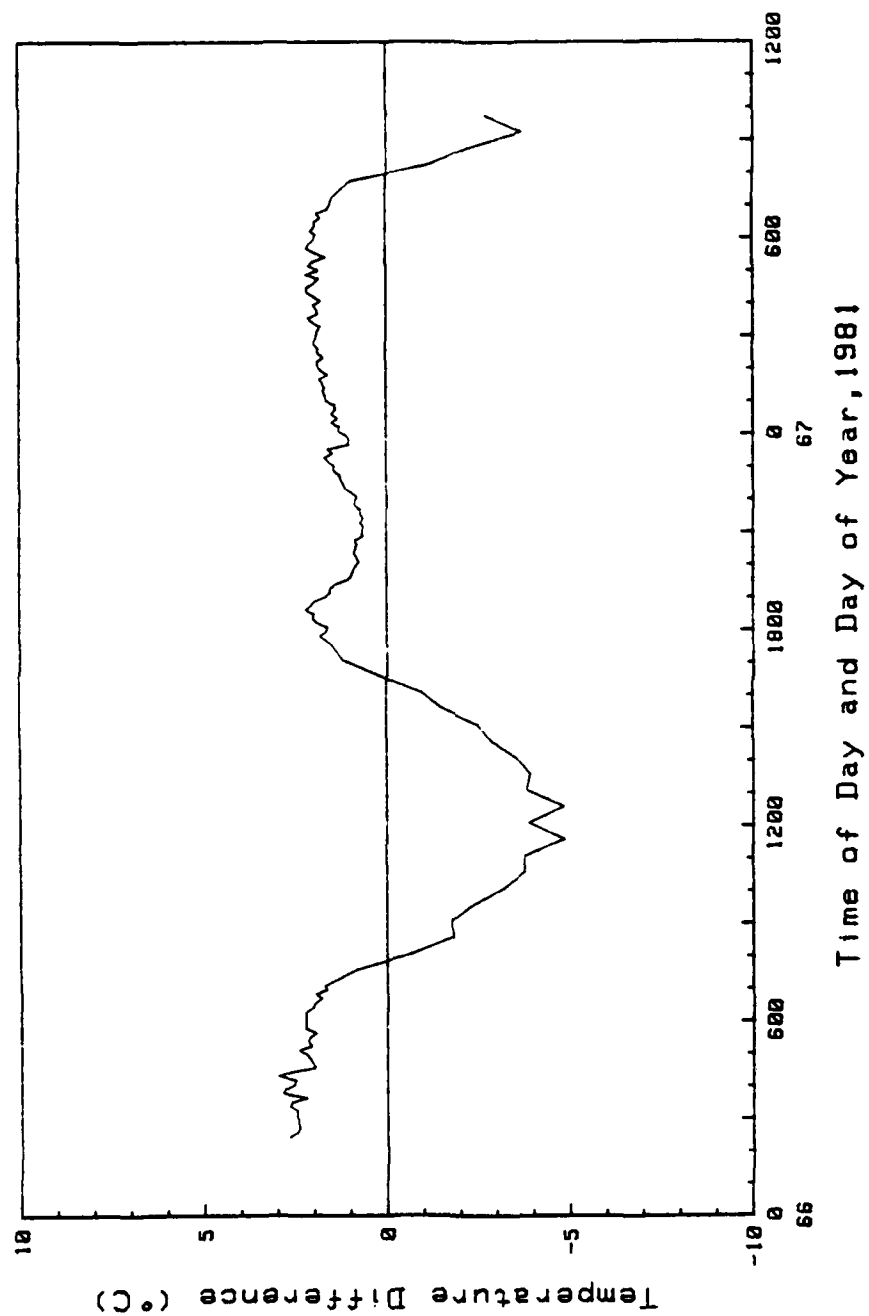


Figure 5. A typical Diurnal cycle of thermal contrast, or brightness temperature difference between the trees and the cut grass background on 6, 7 March 1981.

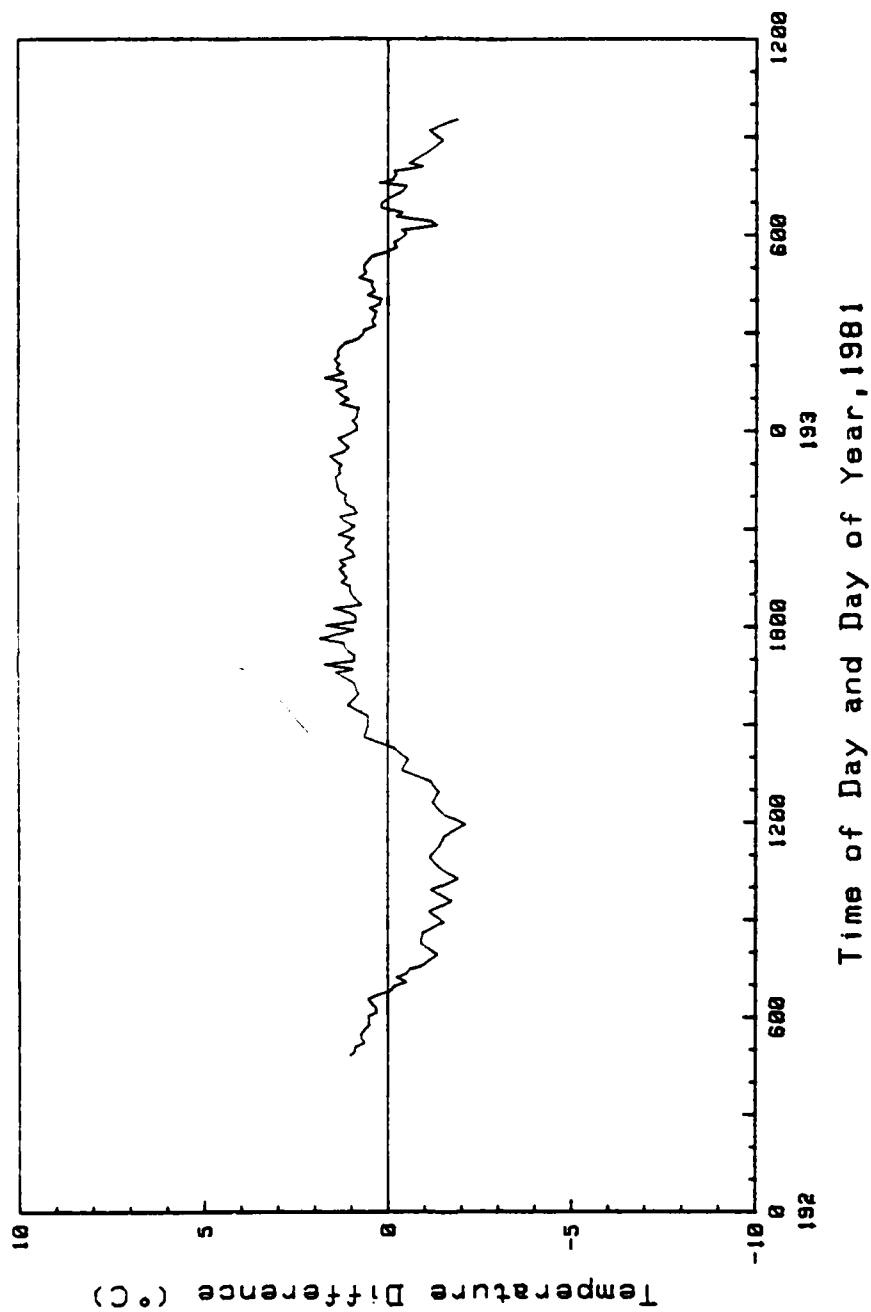


Figure 6. A typical Diurnal cycle of thermal contrast, or brightness temperature difference, between the trees and the cut grass background on 11, 12 July 1981.

Table 1

Seasonal Characteristics of Tree, Background, and Air Temperatures.

Variables		Feb, March	April	July
Diurnal Range of	Grass Background Brightness Temperature	19 <sup>0</sup>	18 <sup>0</sup>	17 <sup>0</sup>
Diurnal Range of	Tree Brightness Temperature	14	16	16
Diurnal Range of	Air Temperature	13	15	16
Air Temperature Min. and Max		-6 to 7	8 to 23	15 to 31
Noon Background-Tree Brightness Temperature Difference		5	3	2
Midnight Tree-Background Brightness Temperature Difference		3.5	2	1

The Change in Thermal Contrast, or Tree-Background  
Brightness Temperature Difference, During the Night

As mentioned previously, in each 24 hour period there were two temperature reversals between the tree and the background brightness temperatures, occurring about 0700 and 1600, varying with time of year. During the day, the background was warmer than the trees. As solar input diminished, the background cooled quickly and the trees slowly, so that about 2 hours before sundown (almanac data) the tree and background brightness temperatures were equal. Then, through the night, tree brightness temperature was above background brightness temperature. Depending upon the level of overcast, heat, and humidity, the time of peak contrast varied from an hour before sunset to 2 to 3 hours after sunset. See Figure 7, Tree-Background Brightness Temperature versus Time from Sundown. Curves are drawn for increments of longwave incoming radiation, which groups data of similar cloudiness and humidity. When it

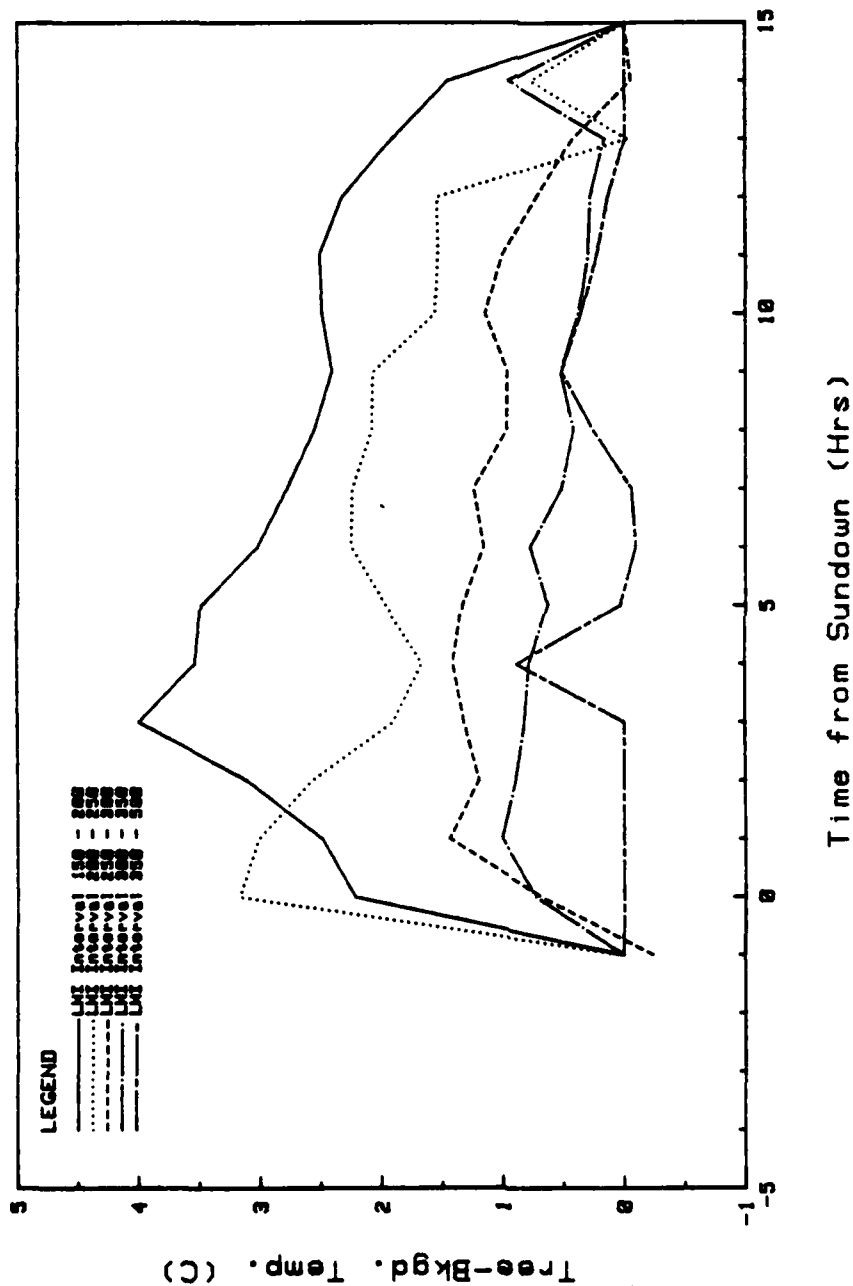


Figure 7. Change in thermal contrast or tree-background brightness temperature difference during the night. Curves are for increments of long wave incoming (LWI) radiation, covering the period from 3 March to 13 July 1981. Low LWI values represent cold, clear, dry conditions. High LWI values represent warm, cloudy, humid conditions.

was very cold and clear ( $150 < L_{wi} < 200 \text{ W/m}^2$ ), the contrast peak ( $4^{\circ}\text{C}$ ) occurred about 2 hours after sunset. For moderate conditions of the spring, fairly clear and not too cold ( $200 < L_{wi} < 250 \text{ W/m}^2$ ), the contrast peak ( $3^{\circ}\text{C}$ ) occurred an hour before sunset. In moderately overcast conditions ( $250 < L_{wi} < 350 \text{ W/m}^2$ ), the peak contrast ( $1^{\circ}$  to  $2^{\circ}\text{C}$ ) occurred at sundown. For hot, humid, cloudy conditions ( $350 < L_{wi} < 500 \text{ W/m}^2$ ), the peak was not well defined or existant. It is only the curves for  $L_{wi} < 250 \text{ W/m}^2$  that a really significant peak occurred. These were fairly clear, cool conditions of early Spring, and it appeared that the time of peak contrast was varying considerably. These relationships can also be observed in Figure 8, a plot of 8 regression curves on the axes of Tree-Background Brightness Temperature versus Long Wave Incoming Radiation,  $L_{wi}$ . Each curve represents a 2 hour interval and the intervals started 2 hours before sundown and proceeded through the night. They rose, up to the time near sundown and slightly following, and then fell steadily as time increased.

#### The Effect of Incoming Long Wave Radiation on Nighttime

##### Thermal Contrast, or Tree-Background Brightness Temperature Difference

Long wave radiation is emitted by everything in an amount proportional to the long wave radiation it receives. The proportion is determined by the object's emissivity, which ranges from 0 to 1. Natural surfaces, in the 8 to 14 micrometer spectral range, have high emissivities, greater than 0.95. Even clouds and the air emit long wave radiation. In an overcast condition, clouds can receive radiation from the sun, the air, the ground, etc. and reradiate back again to the ground. The air emits longwave radiation, depending mostly upon its

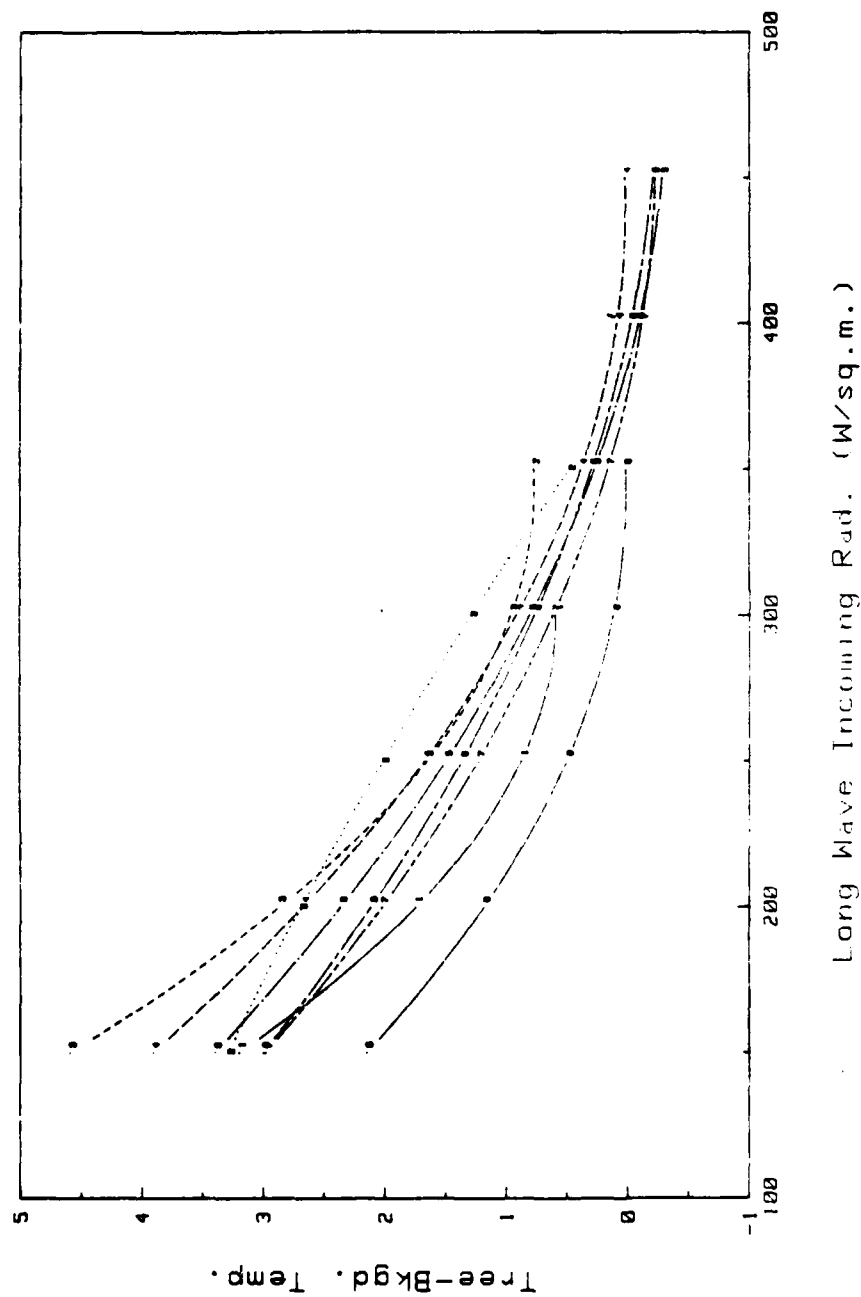


Figure 8. Change in thermal contrast or tree-background brightness temperature difference as a function of long wave incoming radiation, a measure of cloudiness. Separate curves are for 2 hr time increments starting 2 hr before sundown.

moisture content. The thermal image of an area under an overcast sky, then, can be expected to be fairly uniform in temperature as objects and surfaces are continually radiated and reradiated from all sides. The thermal contrast, or tree-background brightness temperature difference, was expected to decrease as long wave incoming radiation increases, and this is exactly what happened, as can be seen in Figure 8, Tree—Background Brightness Temperature versus Long Wave Incoming Radiation. Under the conditions of our experiment at Ft. Belvoir, VA, in February and March, the long wave incoming radiation level never dropped below 150 W/m<sup>2</sup>, which occurred under very clear, cold conditions. Very cloudy and humid conditions in July had long wave incoming radiation levels of 350 to 450 W/m<sup>2</sup>. Therefore, it is obvious that maximum thermal contrast between the ground and objects above the ground will be maximum on clear, cool, dry nights and minimum on cloudy, warm, humid nights. Military targets, such as vehicles with engines running, would probably be more visible on thermal imagery in the latter - cloudy, warm, humid - conditions, when the background clutter (natural thermal contrast) was at a minimum. Vehicles with cold engines should be more visible on thermal imagery under the former - clear, cool, dry - conditions, when they would, like the trees, take on the warmer temperature of the air above the ground. They would, however, be similar to the trees and might be mistaken for trees. Under clear, cool, dry conditions it would be advantageous to hide military vehicles among trees. Under cloudy, warm, humid conditions, the proximity to trees would probably not be very important in hiding vehicles from thermal detection.

The plot of Tree-Background Brightness Temperature versus Lwi may appear odd, in that contrast became negative. It is expected that the

curves would approach  $Y=0$  asymptotically. There are at least two reasons why these do not. 1) During rainfall, contrast is diminished and temperatures become near isothermal, as the trees and ground have their surfaces coated with rainwater. Evaporation of this water, accentuated by wind, will cause cooling and this will be more prevalent on the trees, which have a high surface to volume ratio. This will reduce tree temperature below ground temperature when it would otherwise be higher and cause a negative contrast (tree-background). 2) The curves shown are a set of regression curves, not data, averaging all the data points which occurred from March to July 81. The number of values with high incoming longwave radiation levels was not numerous, and the values were not closely grouped. This means there is more information in the general pattern of the contrast and in the sequence of the time intervals than in the absolute values of the curves.

#### Diurnal Isothermal Conditions

As mentioned previously, tree and background brightness temperatures normally reversed twice every 24 hours, with trees warmer at night and grass background warmer during daylight. See Figure 9, Diurnal Isothermal Conditions and Short Wave Incoming Radiation. Air temperature profile isothermal conditions occur at the nodes of the two air temperature curves. The curves represent air temperature profile differences between the 10cm level and the 120cm level and between the 3m level and the 120cm level, or standard height.

In the morning the tree and background brightness temperature crossover occurred after the air temperature profile crossover. This followed stable, nighttime conditions, and the background took longer to



heat up than the air, having a higher thermal inertia than the air. During our data collection, in the mornings, the air temperature profile crossover occurred from 15 min. to 1 hr. before the tree and background brightness temperature crossover, creating an isothermal condition.

It is not a new discovery that these separate pairs of parameters reverse or come to the same values twice a day, but it is intriguing that all of these parameters come to the same values at about the same time. This creates a uniform temperature condition without much clutter, wherein hot vehicles, above ambient temperature, should be very visible on airborne thermal infrared imagery or in terrestrial infrared imaging devices. Natural occurrences like springs and seeps might well be apparent as cold images then. People or animals may be very visible at an appropriate scale.

On the graph of Figure 9, the nodes near the  $Y = 0$  line, denoting crossovers, or isothermal conditions, are quite apparent during relatively clear conditions, when the daylight short wave incoming radiation ( $S_{wi}$ ) curve is smooth and rounded and reaches a maximum value over  $800 \text{ W/m}^2$ . Daytime curves are smoother partly because data were collected every 1/2 hour instead of every 12 minutes, as was done at night.

#### Seasonal Change of Isothermal Conditions

The curves of the different paired parameters crossover, or reverse, in a consistent pattern with time. The time of day that the tree and cutgrass background brightness temperatures were equal was determined from the graphs of these parameters versus time. The same was done for the reversal of the air temperature profile, especially for the 3m and

10cm levels. A regression curve was developed from each of these sets of data, time of day of crossover vs. day of the year. A regression curve was done for both the morning and the evening crossover. Shown in Figure 10 is the Time of Morning Crossovers versus Day of the Year, 1981.

In the morning, the tree and background brightness temperature crossover and the air temperature profile crossover occurred earlier each day as the year progressed, from March to July, because the days were longer and solar energy was received earlier. The spring equinox occurs on June 21 and this is the longest day of the year, the 172nd day. We should expect the time of crossover to increase after that date if length of daylight is the cause. This still is probably the case, and with more data in the latter part of the year, I would expect to see a curve symmetrical about the 172nd day. More data are required in the winter months also, but it appears that in January and February there would be no difference in the two curves, and true isothermal conditions would exist. After that time, there is a period of relatively isothermal conditions which varies from 15 min. in March to 1 hr. in July.

#### The Diurnal Cycle of the Temperatures of Cut Grass,

#### Uncut Grass, Bare Soil, a Large Truck and the Air

See Figure 11, Brightness Temperature of Plots 1-4 and Truck, and the Air Temperature vs. Time of Day and the Day of the Year, 1982. Bare soil (Plot 2) brightness temperature was normally above all the other plot temperatures at night or during the day, in dry weather. When the bare soil was wet, during the day, it was cooler than the other plots.

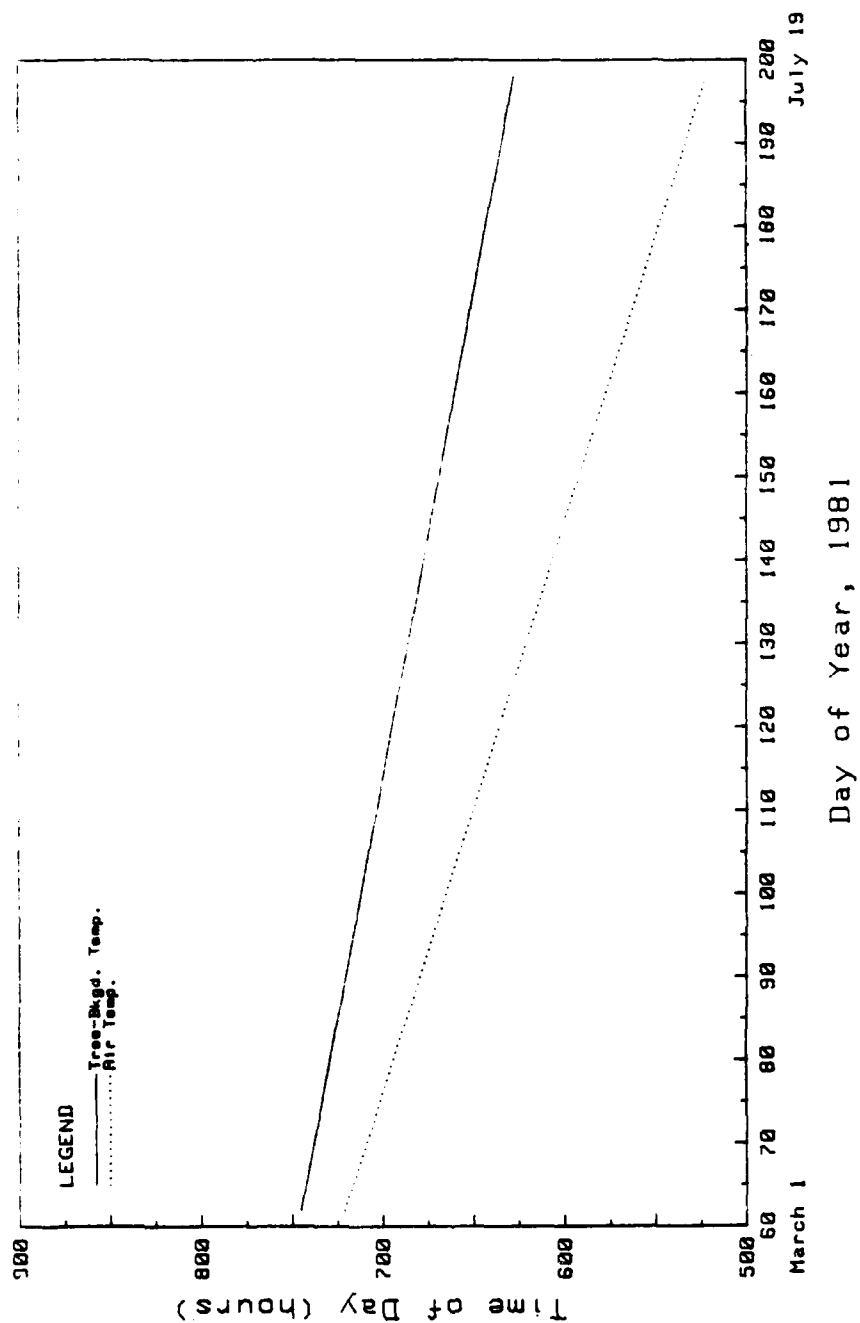


Figure 10. Seasonal change of isothermal conditions from 1 March to 19 July 1981. Two regression curves of the time of morning crossovers of tree and background brightness temperature and of the air temperature profile. Data was determined graphically from plots like Figure 9.

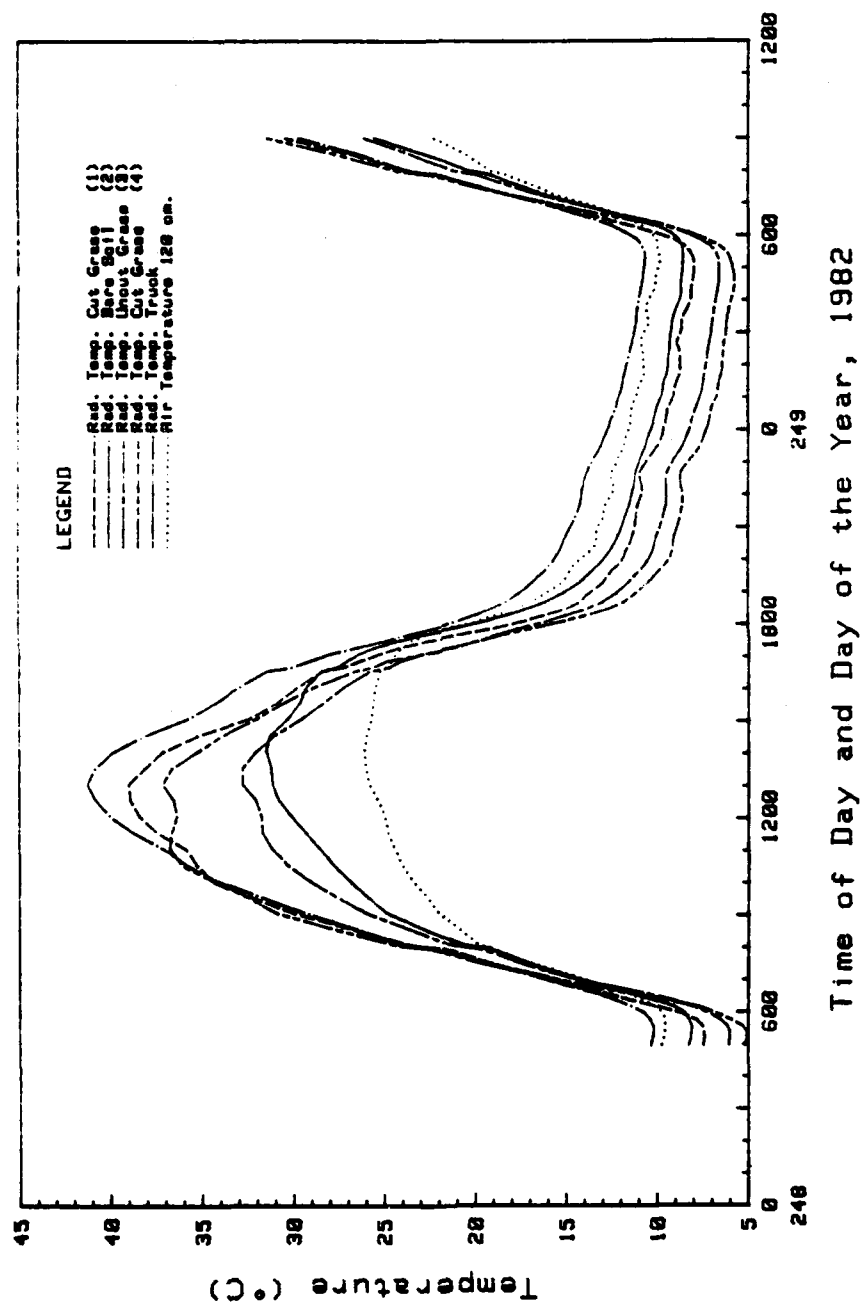


Figure 11. Diurnal cycle of plot and truck brightness temperature and air temperature for 5, 6 September 1982.

Cut grass (Plot 1) brightness temperature was normally the next highest during the day. On wet days it was the highest. This plot was not 100% grass covered, though, and a small amount (15%) was bare soil with dead grass cuttings. The brightness temperature of a second cut grass plot (Plot 4) followed the first through the day, but at night it was the coolest plot, cooler than the uncut grass. This plot was slightly lower topographically, had a higher moisture content, and had a higher percent cover than the other cut grass plot.

The uncut grass (Plot 3) was the coolest ground surface during the day. It was expected to be because of the shadows cast there by tall stems and the larger surface area for transpiration, convection, and radiation.

Truck brightness temperature, engine off, was slightly higher at night than all the plots except the bare plot. During the day it tended to be on the cool side and nearest to the brightness temperature of the uncut grass and second cut grass plots, with its peak lagging that of the other plots by up to 2 hours. Therefore, in the afternoon cooling period, as well as through the night, it was warmer than all but the bare soil and the air temperature.

During the day, air temperature was below all the plot temperatures. At night it was just above plot and truck brightness temperatures but below the bare soil brightness temperature.

In the early morning, as the sun came up, the brightness temperatures of the plots, truck, and air were all about the same as they heated up at the same rate, for several hours. The plots and the truck continued to heat faster than the air. Next the uncut grass, Plot 3, ceased to heat as rapidly and began to level off. The truck brightness temperature most

often began to level off at the same time or before the uncut grass. The second cut grass plot, Plot 4, normally began to level off next. The cut grass, Plot 1, began to level off next, and the bare soil, Plot 2, was still heating, sometimes to as much as  $9^{\circ}\text{C}$  above the other plots.

In the afternoon, the plot, truck, and air temperatures again came together, and crossovers occurred, except that the various crossovers did not occur as close together in time as they did in the morning.

Temperature differences ranged to about  $5^{\circ}\text{C}$ , at any one time, on a clear afternoon. Normally, the uncut grass plot cooled the quickest. It had more biomass for greater transpiration, convection, and radiation cooling, and the surface was more shadowed and cooler during the day.

The two cut grass plots, even if they varied during the day, would come close together in temperature in the late afternoon, usually with Plot 4 cooler than Plot 1 and they would follow the uncut grass plot closely.

The bare soil brightness temperature was usually above all the other plot temperatures, even during afternoon cooling. The soil mass had the highest heat capacity and thermal inertia and changed temperature more slowly, so the bare surface was recharged with heat from below as it radiated and cooled. Air temperature always lagged plot brightness temperatures, as it was affected by them. Just as it warmed up later in the morning, it cooled later in the afternoon. Truck temperature lagged all the other plots, and remained above them, except the bare soil, through the night.

At night, all temperatures slowly decreased, at about  $1/3$  degree per hour, until dawn, when a rapid increase occurred. The brightness temperatures of the various plots separated some after the initial cooling off period at sundown. The bare soil was higher than the rest,

which were grouped together. Truck brightness temperature normally was the next warmest. The first cut grass plot was next, followed by the uncut grass and then the second cut grass plot. Plot 4, cut grass, was coolest at night probably because of its lower topographic position, higher moisture content, and more complete vegetative cover.

June to September Change of the Temperatures of Cut Grass,  
Uncut Grass, Bare Soil, a Large Truck, and the Air

In June during daylight, the bare soil was much warmer than the other plots, by as much as 9°C warmer than the next warmest. By September it was only about 2°C warmer. The bare soil was almost always warmer than the other plots and the air. At night, from June to September, the bare soil stayed 3°C warmer than the cut grass (Plot 1), the next warmest plot.

The cut grass plots (Plots 1, 4) had daytime brightness temperatures midway between the warmer bare soil and the cooler uncut grass. As the year progressed from June to September, the cut grass temperature changed relative position from close to the uncut grass to close to the bare soil in temperature.

Although the daytime uncut grass brightness temperature was up to 3 to 4°C below that for the cut grass, in June, by July and through September it was up to 10 to 11°C below the cut grass brightness temperatures.

During late June, the daytime truck brightness temperature followed the cut grass (Plot 1) brightness temperature. From July through September, it followed the uncut grass (Plot 3) brightness temperature.

Daytime air temperature was below plot and truck brightness temperature through the whole period. In June it was 1 to 3°C cooler than the uncut grass (Plot 3). By early September it was 6 to 7°C cooler. Air temperature stayed warmer and crossed over plot brightness temperatures in the afternoon as they cooled more quickly. Nighttime air temperatures from June to September were normally cooler than the bare soil and warmer than the other plots and the truck.

Daytime temperatures formed three different patterns through the period of June to September:

- 1) In June the cutgrass (Plots 1 and 4) and the truck were close together, with the bare soil (Plot 2) much warmer, and the uncut grass (Plot 3) a little cooler. Air temperature was a little cooler than the uncut grass. See Figure 12.

- 2) In July the cutgrass (Plots 1 and 4) were together, the uncut grass (Plot 3) and the truck were together and a lot lower, and the bare soil (Plot 2) was warmer than the cut grass (Plots 1 and 4). Air temperature was a lot cooler than the uncut grass. See Figure 13.

- 3) In September the cutgrass (Plots 1 and 4) were fairly close together, the bare soil (Plot 2) was a little warmer, the uncut grass (Plot 3) was a lot cooler, and the truck was grouped with the uncut grass (Plot 3) but tended to be cooler. Air temperature was much cooler than the uncut grass. See Figure 11.



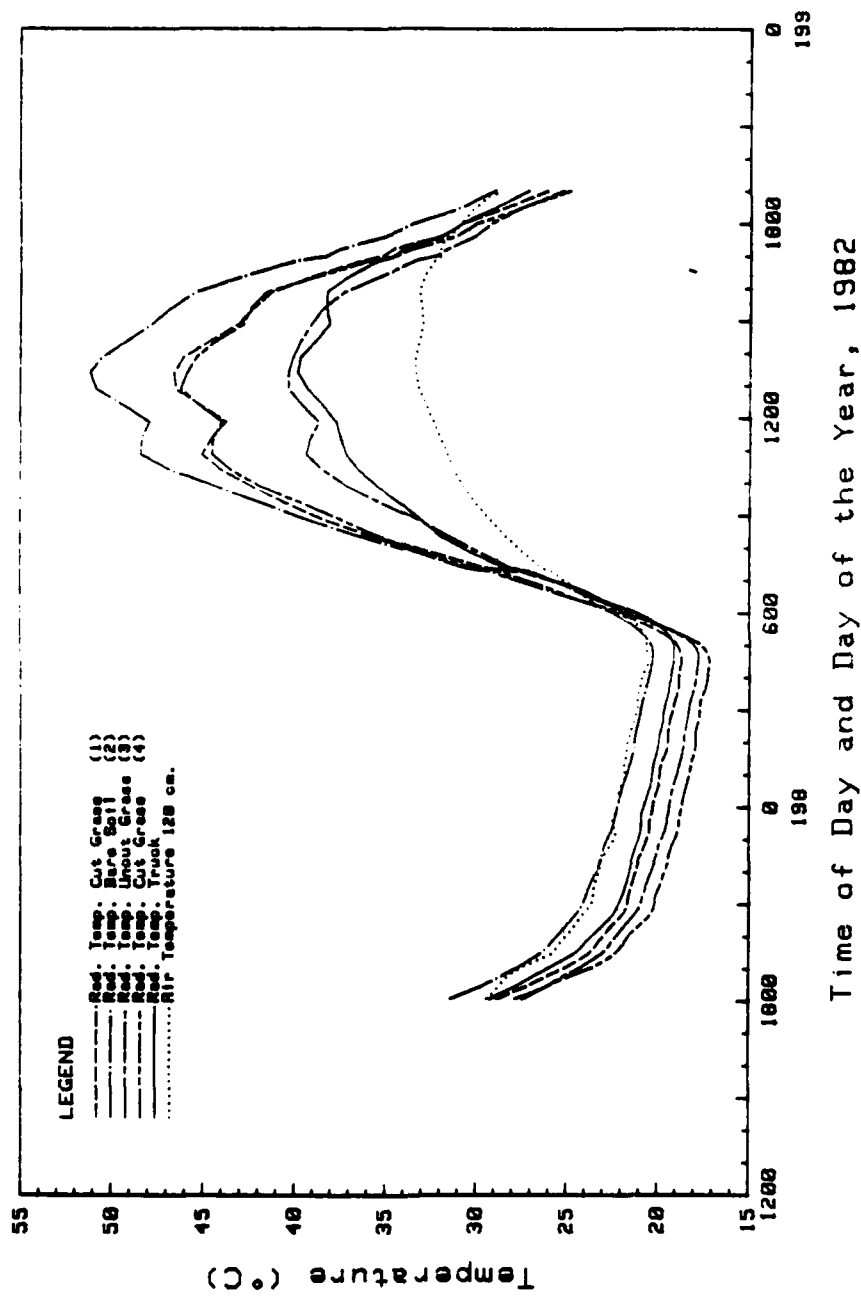


Figure 13. Diurnal cycle of plot and truck brightness temperature and air temperature for 16, 17 July 1982.

The relative arrangement of nighttime brightness temperatures was essentially the same throughout the entire period. The bare soil (Plot 2) was much warmer than the other plots, air temperature was a little cooler than that, the truck was next warmest, the first cut grass (Plot 1) was next warmest, the uncut grass (Plot 3) was next, and the cut grass (Plot 4) was coolest.

The seasonal characteristics of the temperatures of the various plots, the truck, and the air are summarized in Table 2 and Table 3. The data are for specific, clear days which seem to be characteristic. Diurnal ranges are affected by soil moisture at that time.

Table 2

Seasonal Variation in Diurnal Range of Cut Grass, Uncut Grass, Bare Soil, and Truck Brightness Temperatures, and Air Temperature, in degrees Celsius.

Variables (Plot No.)	24 June (175)	17 July (198)	27 August (239)	6 September (249)
Cut Grass (1)	24	28	29	33
Cut Grass (4)	24	29	27	35
Uncut Grass (3)	18	22	23	28
Truck (5)	22	21	22	25
Air Temp.	15	13	15	19

Table 3

Seasonal Variation of Minimum and Maximum of Cut Grass, Uncut Grass, Bare Soil, and Truck Brightness Temperature and Air Temperature, in Degrees Celsius.

Variables (Plot No.)	24 June (175)	17 July (198)	27 August (239)	6 September (249)
Cut Grass (1)	10-34	19-47	9-38	8-41
Cut Grass (4)	9-33	17-46	8-35	5-40
Uncut Grass (3)	10-28	18-40	9-32	7-35
Bare Soil (2)	12-40	20-51	13-44	11-43
Truck (5)	10-32	19-40	11-33	8-33
Air (120 cm.)	11-26	21-33	12-27	10-28

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## APPENDIX A

### Parameters Measured

Air Temperature, Tower 1,	10 cm
Air Temperature, Tower 1,	50 cm
Air Temperature, Tower 1,	120 cm
Air Temperature, Tower 1,	2 m
Air Temperature, Tower 1,	3 m
Air Temperature, Tower 2,	10 cm
Air Temperature, Tower 2,	50 cm
Air Temperature, Tower 2,	120 cm
Air Temperature, Tower 2,	2 m
Air Temperature, Tower 2,	3 m
Air Temperature, Tower 2,	4 m
Air Temperature, Tower 2,	6 m
Air Temperature, Tower 2,	8 m
Air Temperature, Tower 2,	10 m
Air Temperature, Tower 2,	12 m
Soil Temperature, Plots 1-4	1 cm
Soil Temperature, Plots 1-4	4 cm
Soil Temperature, Plots 1-4	10 cm
Soil Temperature, Plots 1-4	20 cm

Parameters Measured (cont'd)

Soil Temperature, Plots 1-4 40 cm

Soil Temperature, Plots 1-4 80 cm

Soil Temperature, Plots 1-4 160 cm

Precipitation, tipping bucket method

Dew Point Temperature

Wind Speed, 120 cm, Towers 1,3

Wind Speed, 15 m, Tower 2

Wind Direction, 15m, Tower 2

Incoming Short Wave Radiation (Swi), 0.28 - 2.8  $\mu\text{m}$

Incoming Long Wave Radiation (Lwi), 3 - 50  $\mu\text{m}$

Net Short Wave Radiation, Plots 1-3

Brightness Temperature Plots 1-4, Truck

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